

USAARL Report No. 2014-08

# Coalition Warfare Program Tactile Situation Awareness System for Aviation Applications: System Development

By Ben D. Lawson  
Angus H. Rupert



United States Army Aeromedical Research Laboratory  
Warfighter Health Division

January 2014

Approved for public release, distribution unlimited.

## Notice

### Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

### Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

### Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

### Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

<b>REPORT DOCUMENTATION PAGE</b>					<i>Form Approved OMB No. 0704-0188</i>	
<small>The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</small>						
<b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b>						
<b>1. REPORT DATE (DD-MM-YYYY)</b>		<b>2. REPORT TYPE</b>			<b>3. DATES COVERED (From - To)</b>	
<b>4. TITLE AND SUBTITLE</b>				<b>5a. CONTRACT NUMBER</b>		
				<b>5b. GRANT NUMBER</b>		
				<b>5c. PROGRAM ELEMENT NUMBER</b>		
<b>6. AUTHOR(S)</b>				<b>5d. PROJECT NUMBER</b>		
				<b>5e. TASK NUMBER</b>		
				<b>5f. WORK UNIT NUMBER</b>		
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>					<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>					<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>	
					<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b>						
<b>13. SUPPLEMENTARY NOTES</b>						
<b>14. ABSTRACT</b>						
<b>15. SUBJECT TERMS</b>						
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>	
a. REPORT	b. ABSTRACT	c. THIS PAGE			<b>19b. TELEPHONE NUMBER (Include area code)</b>	

This page is intentionally left blank.

### Acknowledgements

The authors thank the following colleagues for their help with the preparation of this report: MAJ Timothy Cho, Ms. Catherine Davis, Ms. Melinda Vasbinder, and Ms. Deahndra Grigley.

The authors express their sincere gratitude to the people listed below for their contributions to this project. Without the participation of the following people, this project would never have been initiated or have come to fruition:

- Mr. John Noulis (CAPT, USN, retired), an outstanding aviator, who had the foresight to see the value of tactile cueing as a means of maintaining orientation and reducing aircraft mishaps. John's advocacy at the Coalition Warfare Program (CWP) office was responsible for the initiation of this project.
- Dr. Robert Cheung, our Canadian research counterpart, who kept alive the Canadian interest in this project and maintained the Test Project Agreement (TPA) which leaves open the window for future collaborative efforts.
- The Naval Aviation Center for Rotorcraft Advancement, specifically Mr. Ed McDaniel and Mr. Dan Seifert, who managed and pushed forward the Small Business Innovative Research (SBIR) process, resulting in funding for two, Phase II SBIRs.
- Dr. Arthur Estrada III, who helped extensively with project management, manuscript preparation, and the writing of monthly progress reports necessary to this effort.

This page is intentionally left blank.

## Summary

The Department of Defense (DoD) CWP awarded funding to the U.S. Army Aeromedical Research Laboratory (USAARL) to continue development of the Tactile Situation Awareness System (TSAS) and prepare the TSAS technology for delivery to the aviation rotary-wing community. This is a report of the funded activities and achievements. TSAS is a garment containing vibrotactile stimulators (called tactors) partially covering the torso. The garment provides aircraft flight control parameters intuitively through the sense of touch. The main TSAS application presently being developed is a system to provide hover feedback and control within degraded visual environments (DVE). During simulation and flight tests prior to the CWP effort, pilots demonstrated the ability to non-visually hover helicopters and transition to forward flight using TSAS, while consistently reporting reduced workload and increased situation awareness. Working in conjunction with two SBIR companies, the recent CWP TSAS effort advanced the state of tactile cueing and delivered TSAS garments, avionic interfaces, and software compatible with military helicopter platforms. The system is now suitable for developmental and operational testing in flight during operations of the Army's UH-60 Black Hawk and its variants (the Navy's Sea Hawk, the Air Force's Pave Hawk, and the Coast Guard's Jay Hawk).

This page is intentionally left blank.



## Table of contents

	<u>Page</u>
Introduction .....	1
Engineering deliverables.....	1
Engineering Acoustics’ Inc. SBIR .....	1
Chesapeake Technology International SBIR.....	5
Simulator testing at manned flight simulator, Naval Air Systems Command.....	7
Coalition partner contributions.....	8
Demonstrations .....	8
United States and International acquisition developments.....	9
Conclusions .....	9
Recommendations .....	10
References .....	11
Acronyms .....	12

## List of figures

1. Photos of C-2 tactor, C-3 tactor and EMR tactor .....	2
2. Comparison between conventional and distributed tactor configurations .....	3
3. Distributed tactor system .....	4
4. Prototype of a co-located “hybrid” tactor belt .....	5
5. The full torso garment and seat cushion .....	6
6. The avionics box .....	6
7. The cockpit interface .....	7
8. Graph of last 20 seconds of hover deviation for all DVE flights .....	7

This page is intentionally left blank.

## Introduction

This is a report of recent CWP-funded activities to further develop the TSAS. The concept of employing tactile displays to maintain spatial orientation and situation awareness was introduced at a 1989 Advisory Group for Aerospace Research & Development (AGARD) meeting in Copenhagen (Rupert, Mateczun, and Guedry, 1990) as a way to reduce spatial disorientation mishaps in aviation. Subsequent flight testing in both fixed wing aircraft (Rupert, Guedry, and Reschke, 1994) and rotary wing aircraft (Raj, Suri, Braithwaite, and Rupert, 1998) demonstrated the ability to provide continuous orientation information intuitively via tactile cueing.

In the initial proposal to the CWP in 2007 the budget request was \$2.4 million, which was the estimate required to accomplish the engineering design and construction of the proposed effort. The CWP did not fund the proposal due to limited funds available. During 2007, the TSAS team submitted an SBIR topic via Naval Air Systems Command (NAVAIR) that could assist in the delivery of the desired product. When the SBIR was approved late 2007, the second CWP proposal was submitted for fiscal year (FY) 2008 with a reduced budget request of \$1.1 million with the anticipation of two, phase II SBIRs being awarded to provide additional support of \$1.7 million.

The two companies selected during the SBIR process were Engineering Acoustics Inc., (EAI) and Chesapeake Technology International (CTI). The role of EAI was to design and develop enhanced tactile stimulators as well as develop electronics and software to drive the new tactors. CTI's role was to integrate the tactors and electronics into a garment and provide the avionics interface(s) compatible with the wide variety of sensors in military and civilian aviation platforms.

The initial kickoff meeting was hosted at USAARL in February 2008 with representatives from CWP, Defence Research and Development – Toronto (DRDC-Toronto), Canadian Embassy, and NAVAIR. The program goals and interaction between various components were planned as parts of a 2-year effort. Subsequently, the CWP office requested the program be extended one more year to accommodate changes in funding resources from DoD. The extension to 3 years proved beneficial due to the prolonged time required to initiate contracts for Phase I and Phase II efforts by the SBIR office.

## Engineering deliverables

### Engineering Acoustics, Inc. SBIR

Under a previous SBIR, EAI developed the C-2 tactor which had become the industry standard whenever a robust, reliable tactile stimulator was required. The weaknesses of the C-2 from the perspective of this program were weight, expense, and number of wires that would be required to connect the pilot garment to the aircraft umbilical. The C-3 is a smaller derivative as shown beside the C-2 tactor in figure 1.



Figure 1. Photos of C-2 tactor, C-3 tactor, and EMR tactor.

EAI also developed the eccentric-mass rubber (EMR) tactor to complement the C-2. The EMR weighs less than the C-2 and costs less to manufacture. It also delivers peak displacement of the user's skin at a lower frequency than the C-2 or C-3 do, thus allowing qualitatively different type of signal to be conveyed to the user. During the development of the new tactors, two advances to address the issue of excessive wiring in the umbilical were developed. The first was the use of wireless communication using bluetooth applications. The Army has recently approved wireless headsets for aircrew, and the Air Warrior program office is planning wireless applications in future aircrew garments.

The second solution to reduce the number of umbilical wires is the use of a common system of stimulating both the C-2 and EMR tactors via a distributed system using addressable boards in the garment. Although the distributed system considerably simplifies the umbilical wiring and reduces the complexity of the breakaway umbilical issues, there is a penalty paid in increased garment weight due to the addition of addressable boards. The distributed system provides increased reliability in that a failure of any one wire can be compensated by rerouting the signal through a different channel. This system will work well for the developmental testing and operational testing (DT and OT) phases of development. It is anticipated that the final product will incorporate small, rugged Application-specific Integrated Circuit (ASIC) chips to further reduce weight and increase ruggedness and reliability in austere environments.

SBIR Phases I & II identified the complexity, weight, and cost associated with vibrotactile arrays. In fact, the weight of the wiring can be larger than the tactor components (for large arrays driven with differential wiring). Therefore, in an effort to reduce the complexity and overall weight of the wearable tactile array components, EAI developed the Distributed Tactor System.

The Distributed Tactor System consists of a bus master (mounted within the TSAS controller) and a node/super-node configuration of driver boards co-located with C-3 (or EMR) tactors at various places around the body connected via a three-wire bus. This concept is shown in figure 2 for a torso belt and seat cushion each containing tactors. The conventional approach requires multiple controllers and discrete wiring (two conductors) to each tactor. The Distributed Tactor systems have miniature, addressable controllers co-located with the tactor, so multi-element tactile arrays can be driven with a single controller and a three-wire bus. The Distributed Tactor System can also be configured with a six-wire bus, and controllers can be implemented to

include redundancy to improve reliability. Figure 3 shows a schematic of the conventional wiring approach, followed by the approach employed in the Distributed Tactor System.

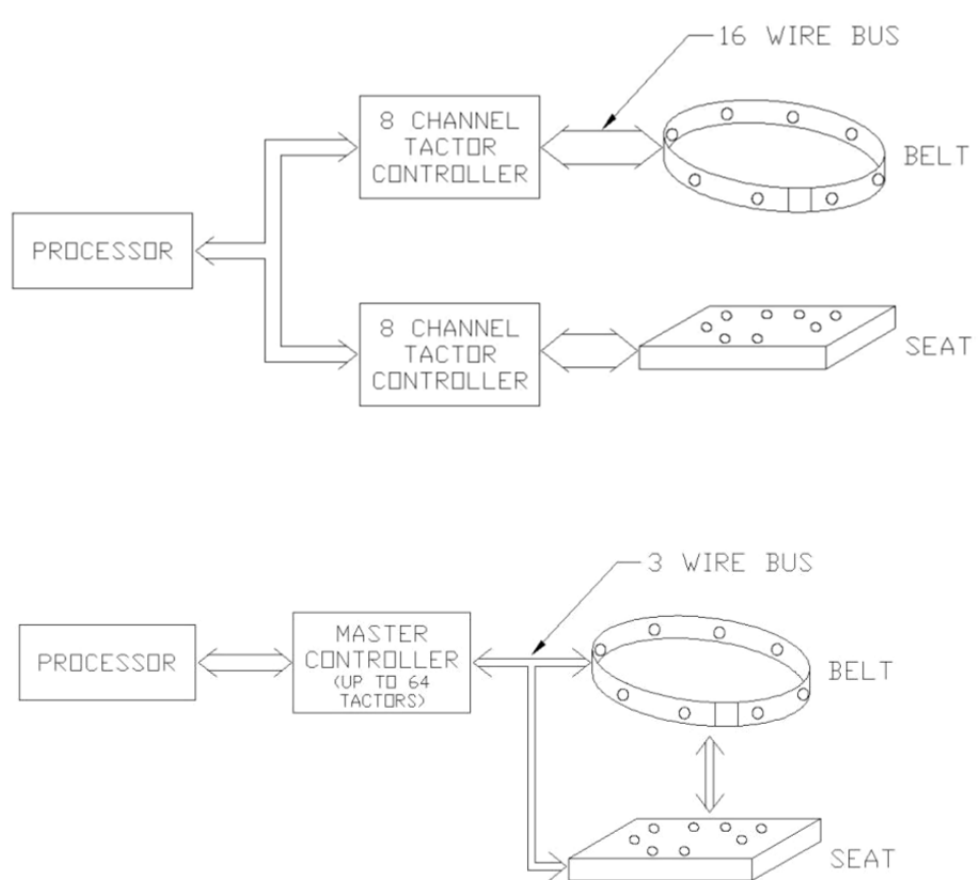


Figure 2. Comparison between a conventional tactor configuration and the Active Tactile Array Cueing (ATAC) Distributed Tactor System linked with a three-wire bus.

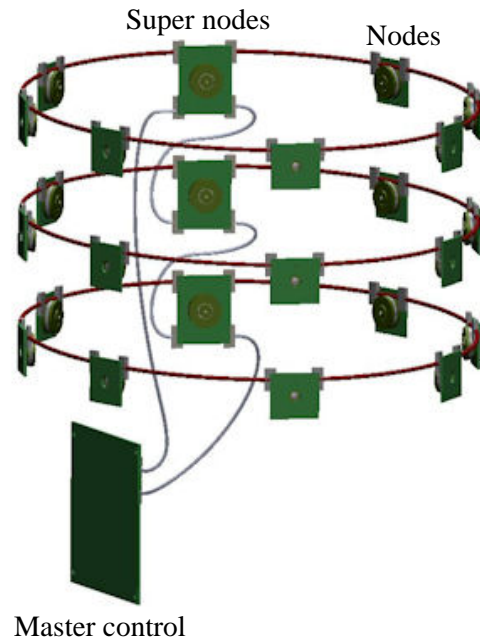


Figure 3. Distributed Tactor System comprising a master control unit (bottom left), a number of rings containing nodes (small units arranged in rings), and super-nodes (large units), all linked with a three-wire circular bus.

A system optimization study showed that cost and reliability improvements could be met for reduced systems (requiring fewer tactile array nodes). An independent research and development (IR&D) effort resulted in the development of the Hybrid Tactor Array (HTA) belt shown in figure 4. The HTA is a tactor belt in which two rows of different types of tactors (EAI's C-3 and EMR) are located around the torso. These tactors operate at different frequencies and have distinctive pulse characteristics, thereby providing different vibrational stimuli that can be easily distinguished. The spatial locations of the tactors (rows) also provide additional spatial dimensionality for differentiating between symbology constructs. This approach potentially facilitates transitioning from one display mode (for example drift cues) to another mode (for example warning cues).

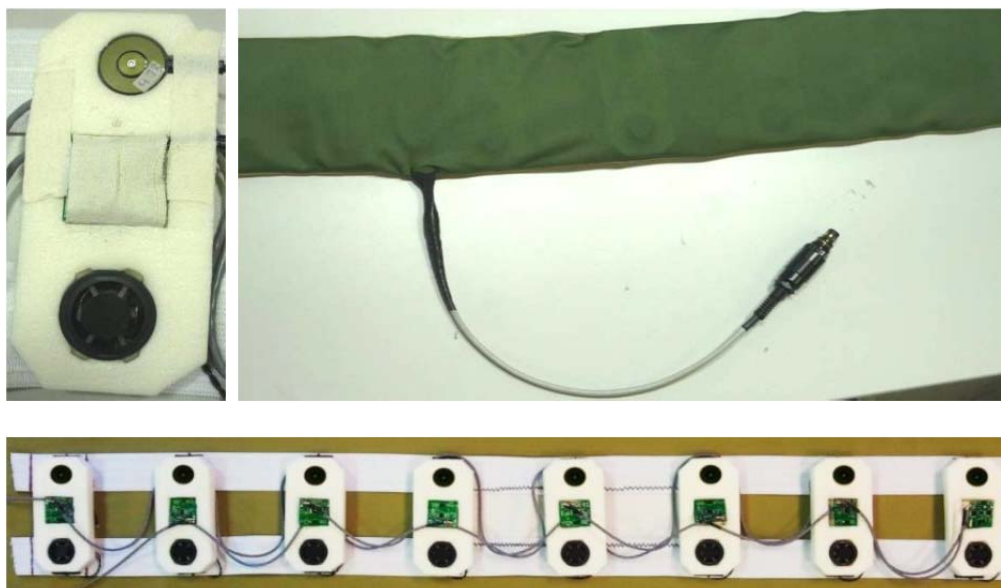


Figure 4. Prototype of a co-located “hybrid” tactor belt comprising lightweight C-3 linear actuators and low frequency EMR tactors. The design is based on a distributed controller electronics architecture with electronics located within the belt minimizing wiring. The top view shows a close up of the actuators and electronics within one pod; the lower view shows the completed belt mounted in a stretchable elastic enclosure (16 tactors in total).

There are several advantages in considering wearable belts (as opposed to vests) for TSAS. First and foremost, belts are easier to don and the fabric technology has a 40 percent stretch, which allows for a wide range in sizing. Further, the dual row, multi-tactor technology offers advantages in reliability, tactile salience, and system weight. EAI has continued improving the belt system, which together with the seat and shoulder harness embedded tactors, will likely be the first system implemented in military helicopters during the spiral development toward the full torso coverage in an Air Warrior garment. This sequential development was recommended by U.S. Air Force (USAF) and U.S. Army special operations pilots during the development of the TSAS Joint Operational Requirements Document (JORD) by Special Operations Command (SOCOM).

A technology that can further enhance the distributed system is the “flip chip” which can provide the opportunity for each tactor to incorporate its own amplifier and address on the distributed system. There were not sufficient funds in the SBIR program for EAI to pursue this technology path.

#### Chesapeake Technology International SBIR

The integration or embedding of tactors and wiring into military-approved garments while ensuring a consistent contact interface in close proximity to the skin is a difficult task. CTI has successfully incorporated the distributed system into garments that can now be used for DT and OT testing (figure 5).



Figure 5. The full torso garment (left) is fitted with a distributed tactor system, and the seat cushion (right) is fitted with eight additional tactors before incorporation into the H-60 seat cushion.

The development of software programs and hardware that can be interfaced with a variety of military helicopter platforms including legacy aircraft was accomplished by incorporating several bus types, e.g., 1553 and Aeronautical Radio, Inc. (ARINC) connectivity, as well as an embedded global positioning system (GPS) and inertial navigation system (INS) (combined GPS/INS) for legacy aircraft. The CTI system (figures 6 and 7) has passed all Electro-Magnetic Interference (EMI) testing and has been integrated to the USAARL UH-60 and helo platforms at NAVAIR.



Figure 6. The avionics box contains the combined GPS/INS (front two-thirds) and the TSAS electronics (rear one-third) for a fully self-contained system to permit flight testing in legacy aircraft with minimal avionics or lacking 1553 / ARINC connectivity. The interfaces on the front include connections for 1553 and/or ARINC bus, power, pilot control unit and outputs to TSAS seats, torso garment, and shoulder harness.





Figure 7. The cockpit interface provides control to the pilots to select the desired mode of operation, for example on/off, hover, glide path, or navigation.

#### Simulator testing at manned flight simulator, Naval Air Systems Command

The CTI team, in coordination with NAVAIR, conducted simulator testing of TSAS hardware and software on 16 and 17 September 2010 with 10 operational pilots at the manned flight simulator (MFS). The full test report (in preparation) confirms that these pilots, with minimal training, were able to use TSAS to maintain a stable hover in severe brownout conditions. The following graph (figure 8) shows what happened during this test as the DVE went from 95 to 99 percent brownout over the last 20 seconds of a 1-minute sample of hover deviation data. Between seconds 45 to 50, the visual cues gradually became insufficient to maintain hover. If the pilots did not have the TSAS cues available, they drifted more than three times further from their designated hover location by the end of the minute.

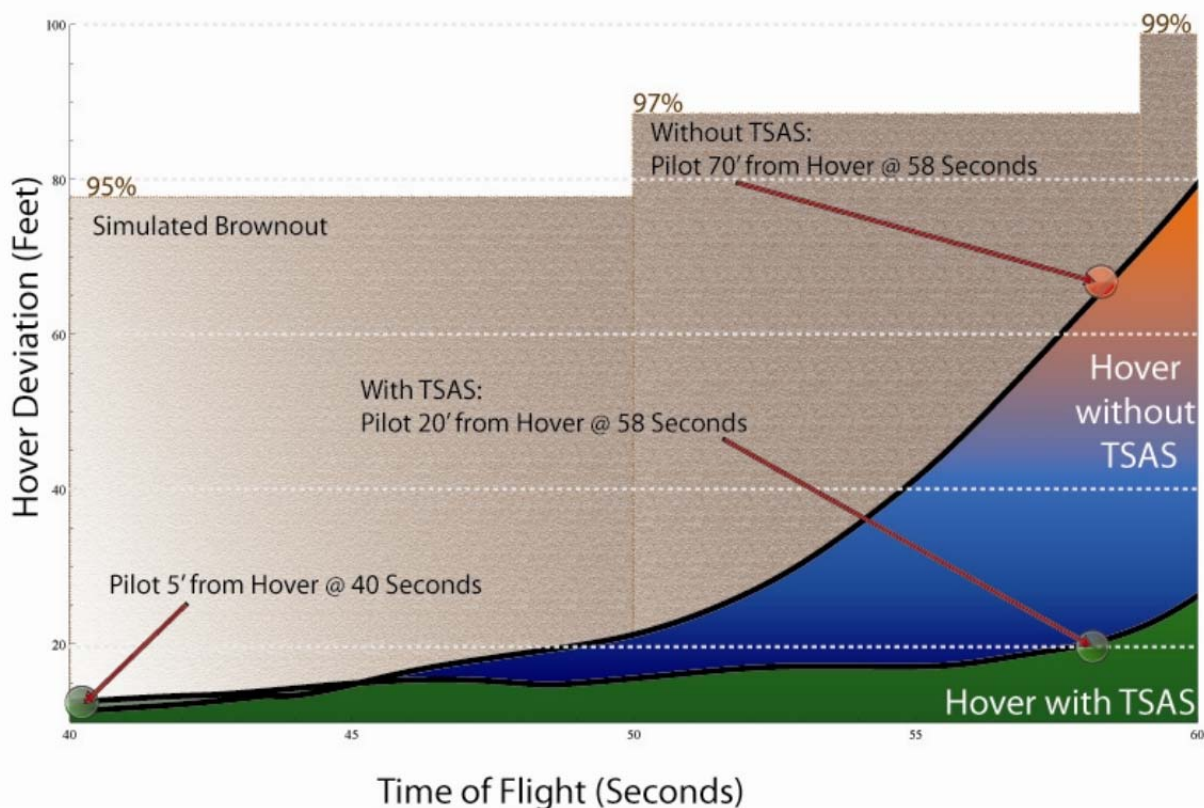


Figure 8. Graph of last 20 seconds of hover deviation for all DVE flights.

Testing was completed in accordance with standards for handling and performance for military rotorcraft (U.S. Army Aviation and Mission Command, 2000). The reason for using this standard was to ensure that the results found could be compared to past and future test results. Figure 8 shows the results from this set of testing scenarios. A 60-second timeline was used with an increasingly DVE to simulate real world brownout conditions. This graph focuses on the last 20 seconds of the test summaries (from time 40 through 60 seconds) when the visual obscuration was the heaviest. At 40 seconds, the DVE was rated at 95 percent and with TSAS engaged, the pilot was able to hover within +/- 5 feet of the intended position.

At 97 percent visual degradation, when TSAS was not engaged, each of the pilots remarked that they had lost all visual indications and this is where they would normally leave the hover area. Note this is where the deviation increases dramatically. With TSAS engaged, the pilots were able to maintain a safe hover throughout increasing visual degradation through 99 percent. Due to time resource limitations, the testing was curtailed at 60 seconds.

As is shown in this report, there is clear evidence that TSAS enables a pilot to maintain a safe hover in degraded visual conditions. Additional testing should be accomplished and TSAS algorithms should continue to be reviewed and upgraded for more extensive testing in the future.

#### Coalition partner contributions

The contributions to TSAS from Canada have been continuing for many years. The first garment used for the TSAS program was developed at the Defence and Civil Institute of Environmental Medicine (DCIEM), recently renamed DRDC-Toronto. The initial air cooled garment was developed commercially by Mustang Survival, headquartered in Vancouver, Canada. In the current CWP-funded effort, CTI initially continued the relationship with Mustang to incorporate tactors and electronics into the torso garments developed in Vancouver and seen in the EAI photo (Figure 5).

DRDC-Toronto, under the guidance of Dr. Robert Cheung, has for the past several years continually sponsored in-flight research using TSAS in combination with novel visual displays such as the Brown-Out Symbology System or Brown-Out Symbology Set (BOSS), developed at the Ames Research Center of the National Aeronautics and Space Association (NASA). Additionally, Dr. Cheung has funded simulator-based research at USAARL for the past 2 years to determine the value of TSAS for helicopter search and rescue (SAR) operations. These data have been collected and are undergoing analysis.

#### Demonstrations

Over the 3-year lifespan of this CWP project, there have been multiple presentations and demonstrations using fixed- and motion-based simulators. Largely as a result of the demonstrations in Washington D.C., the Defense Safety Oversight Council (DSOC) approved an FY 2011 program to socialize TSAS using a portable training simulator. The DSOC effort developed a side-by-side TH-57 helicopter simulator that has been used to provide demonstrations in FY 2011 at the following conferences: the Army Science Conference (ASC),

the Air Force Association for Air Warfare meeting, the Army Aviation Association of America meeting, the DSOC annual meeting, and at meetings in the Pentagon. Senior leadership who were briefed included the Honorable Zachary Lemnios, Assistant Secretary of Defense for Research and Engineering (ASD R&E); the Honorable Katherine Hammack, Assistant Secretary of the Army, Installations, Energy, and Environment (IE&E); and many General Officers. The most important purpose of these communications and this CWP program was to develop a TSAS that will permit DT and OT by potential sponsors and platform program managers.

### United States and International acquisition developments

The ultimate goal of the TSAS CWP was to place the technology on U.S. and Coalition Warfare platforms to improve pilot performance and reduce mishaps. We have actively worked with the Army Concepts & Requirements Directorate (CRD) for the past 5 years on the documentation that has led to a formal requirement. The TRADOC Program Office - Aviation Brigades (TPO-AB) has included TSAS into the solutions set of its requirements documents. The Functional Needs Analysis (FNA), the Functional Solutions Analysis (FSA), and the Initial Capabilities Document (ICD) for aircraft survivability and DVE have each been approved and signed. The FSA has TSAS liberally spread throughout the document as a solution for DVE. The ICD will continue to be developed into a Capability Development Document (CDD), which is the Milestone B point in the acquisition process. The typical time required to develop this document should result in a signed CDD in FY 2016.

The Air Warrior program, which is programmatically under Program Executive Office Soldier (PEO Soldier), has included tactile cueing in the CDD for Air Soldier System (Air SS). In the first year of research, development, test, and evaluation (RDT&E) funding the TSAS was not included for funding by Air SS.

The Project Manager's Office for Utility Helicopters (PM Utility) controls the UH-60, which represents the single largest number of helicopters by type within the Army (and the greater DoD). PM Utility has endorsed TSAS (PM Utility, 2010) and, following successful flight testing, may include TSAS as part of the upgrade of the UH-60 Alpha model to Lima model conversion.

Australia has indicated a desire to actively pursue TSAS following a demonstration on August 2010 at USAARL to MG David Morrison the current Chief of Australian Army. A cooperative research and development agreement and material transfer agreement (CRADA/MTA) was signed between USAARL and Australia, which will permit the loan of TSAS equipment and technology to Australia. This project is on hold pending funding from Australia.

### Conclusions

The TSAS CWP has developed and delivered the desired products (avionics and garments) in a timely fashion, which will facilitate DT and OT of the TSAS technology. The new system has been shown to reduce hover deviation during flight. Additionally, the CWP socialization effort has resulted in international interest with requests for in-flight evaluation of TSAS. A key accomplishment derived from the successful results of this project is the formal inclusion of the

TSAS in the Army' aviation requirements. PM Air Warrior has included TSAS in its suite of various DVE solutions, while PM Utility has signed a letter of endorsement to move forward with additional flight testing. Our ultimate goal is to improve pilot safety and performance by transitioning this capability into helicopter cockpits where appropriate for military or civilian applications, e.g., to assist pilots during emergency medical evacuation.

### Recommendations

- a. Improve and disseminate the distributed TSAS beyond the current prototype stage. This will be accomplished by seeking additional funding to modify the system for manufacturing and commercialization of multiple units. This will enable TSAS to be purchased readily by developers within the United States and other countries.
- b. Maintain government ownership and control of the TSAS software as additional government funding becomes available and the system is disseminated. This can be done by including the appropriate verbiage in future government contracts to industry partners or small businesses.
- c. Arrange a meeting between the three services and Coast Guard to coordinate the next stage of flight testing and requirements, based on the positive results seen from the current CWP program. This meeting will resolve cross-service integration and transition issues, ensure stakeholder input, and foster a proper understanding and use of the technology among the services.

## References

- U.S. Army Aviation and Missile Command. 2000. Aeronautical design standard performance specification handling qualities requirement for military rotorcraft. Redstone Arsenal, AL. ADS-33E-PRF.
- Rupert, A. H., Mateczun, A., and Guedry, F. E. 1990. Maintaining spatial orientation awareness. In Situation Awareness in Aerospace Operations, AGARD CP-478: 21-1, Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development.
- Rupert, A. H., Guedry, F., and Reschke, M. 1994. The use of a tactile interface to convey position and motion perceptions. In Virtual Interfaces: Research and Applications, AGARD CP 541, Neuilly Sur Seine, France: Advisory Group for Aerospace Research and Development.
- Raj, A. K., Suri, N., Braithwaite, M. G., and Rupert, A. H. 1998. The Tactile Situation Awareness System in rotary wing aircraft: Flight test results. In Proceedings of the RT/HFM Symposium on Current Aeromedical Issues in Rotary Wing Operations, 16: 1-7.
- PM Utility. (2010, Feb 7). [TSAS Endorsement Letter]. PEO Aviation, Redstone Arsenal, Wood Road, Huntsville, AL, 35898.

## Acronyms

Air SS – Air Soldier System

AED – Army Aviation Engineering Directorate

AGARD – Advisory Group for Aerospace Research and Development

ASD R&E – Assistant Secretary of Defense, Research and Engineering

ARINC – Aeronautical Radio, Inc.

ASC – Army Science Conference

ASIC – Application-specific Integrated Circuit

ATAC – Active Tactile Array Cueing

BOSS – Brown-Out Symbolology System/Set

CRADA/MTA – Cooperative Research and Development Agreement/Material Transfer Agreement

CDD – Capability Development Document

CRD – Concepts and Requirements Directorate

CTI – Chesapeake Technology International

CWP – Coalition Warfare Program

DCIEM – Defence and Civil Institute of Environmental Medicine

DCS – Deputy Chief of Staff

DND – Department of National Defence

DoD – Department of Defense

DRDC – Defence Research and Development Canada

DSOC – Defense Safety Oversight Council

DT – Developmental Testing

DVE – Degraded Visual Environments

EAI – Engineering Acoustics, Inc.

EMI – Electro-Magnetic Interference

EMR – Eccentric Mass Rubber

FNA – Functional Needs Analysis

FSA – Functional Solutions Analysis

FY – Fiscal Year

GPS – Global Positioning System

HTA – Hybrid Tactor Array

ICD – Initial Capabilities Document

IE&E – Installations Energy and Environment

INS – Inertial Navigation System

IR&D – Independent Research and Development

JORD – Joint Operational Requirements Document

MFS – Manned Flight Simulator

NACRA – Naval Aviation Center for Rotorcraft Advancement

NASA – National Aeronautics and Space Administration

NAVAIR – Naval Air Systems Command

NRC – National Research Council

OT – Operational Testing

PM Utility – Project Manager, Utility

PEO Soldier – Program Executive Office, Soldier

RDT&E – Research, Development, Test, and Evaluation

SAR – Search and Rescue

SBIR – Small Business Innovative Research

SOCOM – Special Operations Command

TPA – Technical Report Agreement

TPO-AB – TRADOC Program Office -Aviation Brigades

TRADOC – U.S. Army Training and Doctrine Command

TSAS – Tactile Situation Awareness System

USAARL – U. S. Army Aeromedical Research Laboratory

USAF – U. S. Air Force





Department of the Army  
U.S. Army Aeromedical Research Laboratory  
Fort Rucker, Alabama, 36362-0577  
[www.usaarl.army.mil](http://www.usaarl.army.mil)



U.S. Army Medical Research and Materiel Command